

DO NLS1S AND ULTRASOFT AGN HAVE IRRADIATED WARPED ACCRETION DISKS?

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ABSTRACT

When Beppo-SAX measured the 0.1 to 12 keV spectrum of RE J1034+396, observations in the optical, UV and EUV were also taken within a few weeks. This multi-wavelength spectrum placed very strong constraints on its unusually hot big blue bump component, which has been attributed to a high (almost Eddington) rate of accretion onto a disk surrounding a low mass black hole. However, while a simple, geometrically-thin accretion disk provides a good fit to the UV to X-ray continuum, it leaves a residual flat and featureless component in the optical. We propose that the disk is actually flared or warped and that the central ionizing EUV/X-ray continuum is irradiating the outer parts of the disk and boosting the optical/UV continuum flux. The relatively narrow permitted lines may be due to a resulting disk wind. This physical interpretation may explain the link between ultrasoft X-ray excesses and broad line velocity in the AGN class as a whole. It may also have implications for the possible relationship between ultrasoft AGN and galactic black holes.

Key words: accretion, accretion disks – line: profiles – galaxies: individual (RE J1034+396) – galaxies: Seyfert – ultraviolet: galaxies – X-rays: galaxies

1. INTRODUCTION

The optical to X-ray continuum of RE J1034+396 is highly unusual for a Seyfert 1 galaxy. The optical/UV continua of most AGN rise towards the blue with a slope $\alpha \sim 0.4$ (where α is the spectral index, defined such that $F_\nu \propto \nu^{-\alpha}$), and the soft X-ray spectrum falls towards high energies with spectral index $\alpha \sim 2$ (e.g. Laor et al. 1997). The spectrum seems to peak in the unobservable EUV and this continuous, optical to soft X-ray feature known as the ‘big blue bump’ (BBB), is believed to represent the emission from a geometrically thin, optically-thick accretion disc (AD).

In RE J1034+396 however, the optical/UV continuum is flat ($\alpha \sim 1$) with no sign of the BBB down to Ly α . At ~ 0.1 keV, the soft X-ray spectrum is very strong above the extrapolated level of the optical/UV continuum, peaking at ~ 0.3 keV (Puchnarewicz, Mason & Siemiginowska 1998).

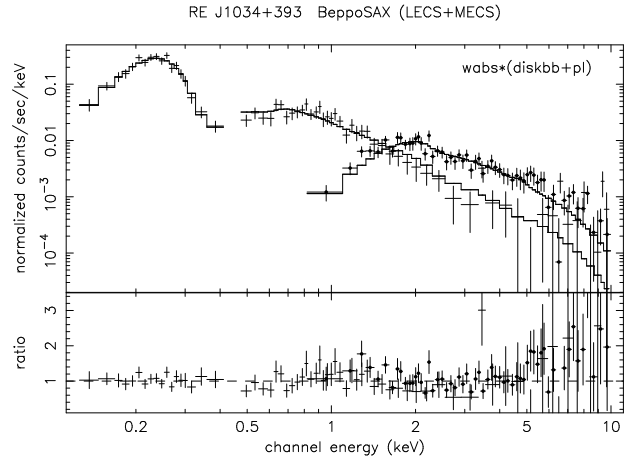


Figure 1. Disk blackbody plus power law fit to the 0.1–10 keV Beppo-SAX spectrum.

The Beppo-SAX spectrum (0.1 to 10 keV) is shown in Figure 1. It was best-fit by Soria & Puchnarewicz 2002 using a Comptonized disk blackbody with a temperature at the inner edge of the disk, $T_{\text{in}}=120$ eV and a coronal temperature $T_{\text{C}}=15$ keV.

The multiwavelength (8000 Å to 10 keV) spectrum, comprising quasi-simultaneous optical, UV and X-ray data, was measured in January 1997 and fitted with a combination of blackbody and power-law models (Puchnarewicz et al. 2001). A simple geometrically-thin AD was not sufficient to reproduce this spectrum so an underlying optical to X-ray power-law component with $\alpha \sim 0.6$ was added in. Breeveld & Puchnarewicz 1998 investigated the possibility of a BL Lac-type of component for this power-law but no compelling evidence for the physical origin of the ‘power-law’ was found. The multiwavelength spectrum used in the fits is shown in Figure 2. The AD and power-law components are plotted separately so that the shortfall in the optical/UV can be clearly seen. The fits inferred a high accretion rate (L 0.3–0.7 L_{Edd}), a small black hole mass, $M \sim 10^6 M_{\odot}$ and a viewing angle of 60–70°. Thus they concluded that RE J1034+396 had a low-mass black hole accreting close to the Eddington limit.

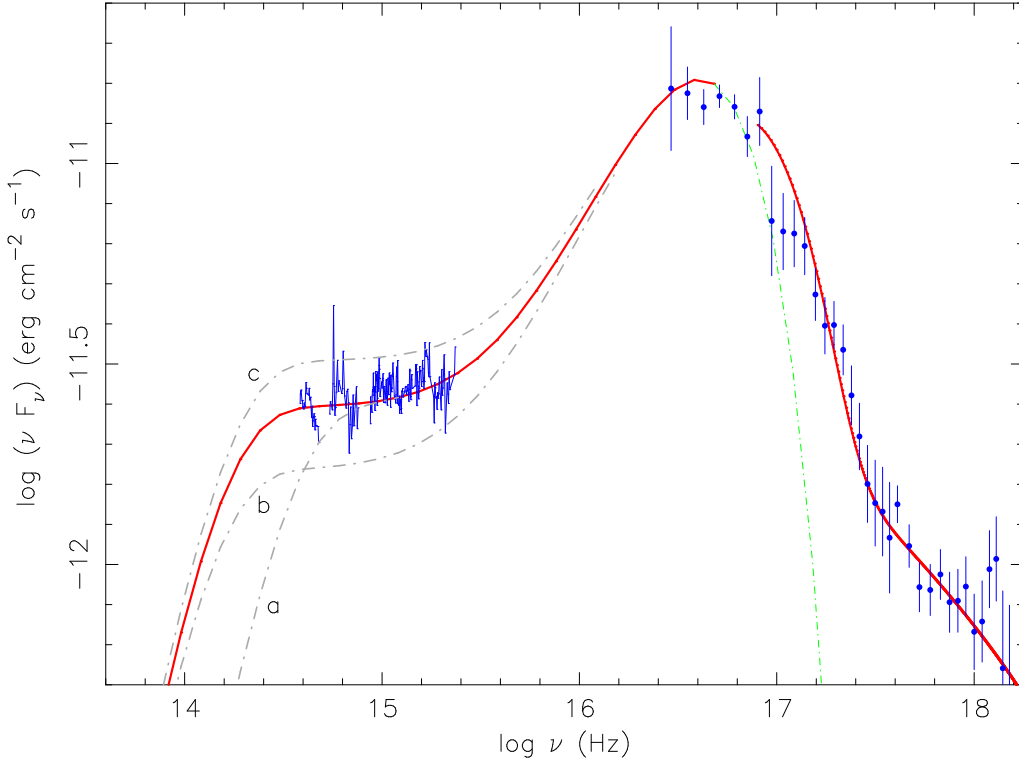


Figure 3. Broadband spectral fit to the WHT, HST, and Beppo-SAX observed fluxes ($E \leq 7$ keV). (The line-of-sight Galactic absorption has been removed.) The thick solid line for $\log \nu < 16.7$ represents the low-energy part of an irradiated disk blackbody spectrum, continued as a dash-dotted line for $\log \nu > 16.7$. The thick solid line for $\log \nu > 16.9$ represents the X-ray spectral fit, physically interpreted as a disk blackbody modified by Comptonisation. The temperature at the inner edge of the disk $kT_{\text{in}} = 0.1$ keV. The meaning of the curves labelled 'a', 'b' and 'c' is discussed in the text.

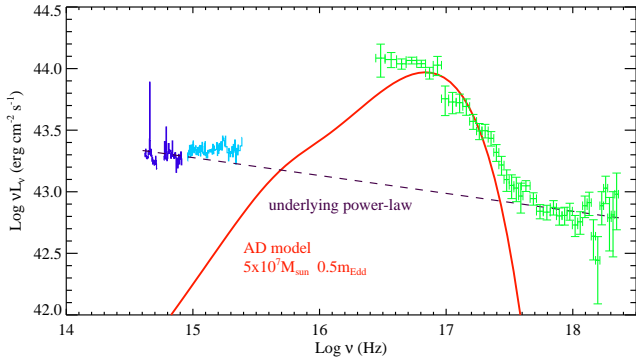


Figure 2. The multiwavelength spectrum of REJ 1034+396 (optical in dark blue; HST-UV in light blue; Beppo-SAX in green) compared with the best-fitting AD model (solid red) and power-law component (black dashed).

2. A WARPED, OR FLARED, ACCRETION DISK

The effective temperature of an AD photosphere at each radius is determined by the thermal energy generated by local viscous dissipation near the disk mid-plane (viscous heating), as well as by the energy intercepted from the

central X-ray source, thermalised and re-emitted (irradiative heating).

In a geometrically-thin, optically-thick AD, at a given radius R , the temperature is proportional to $R^{-3/4}$. However, if the disk is irradiated, then the temperature, T_{irr} , is proportional to $R^{-1/2}$ and irradiative heating will dominate over viscous heating at large radii. If the disk is flared or warped then emission due to irradiation will be relatively strong in the optical/UV, where it intercepts more of the ionizing continuum. The spectrum will then flatten at these wavelengths. This provides a straightforward solution to the origin of the flat optical/UV continuum.

The continuum spectrum at energies $\lesssim 0.3$ keV can be well fitted by a diluted disk blackbody spectrum [thick (red) solid line in Figure 3] with a spectral hardening factor, $f = 1.5$ ($f=1$ for an AD which is not irradiated), and a temperature at the inner edge of the AD of ~ 100 eV (see Table 2 in Soria & Puchnarewicz 2002 for full details of the best-fit parameters). The best-fit model is shown in Figure 3. Irradiation is dominating at a radius, $R_{\text{irr}} \gtrsim 80 R_{\text{inn}}$. For models b and c in Figure 3, irradiation dominates at $R_{\text{irr}} \gtrsim 110 R_{\text{inn}}$ and $R_{\text{irr}} \gtrsim 50 R_{\text{inn}}$ respectively.

The outer disk radius is also constrained by our fit: we require $R_{\text{out}} \gtrsim 5 \times 10^{16} \text{ cm} \approx 3 \times 10^5 GM/c^2$. If we keep all other parameters in the best-fit model fixed, but assume a disk truncated at $R_{\text{out}} = 10^{16} \text{ cm}$, we cannot reproduce the flat optical spectrum (curve marked 'a' in Figure 3).

The black hole mass, $M \sim 10^6 M_{\odot}$. At this mass, the value of the innermost stable orbit from this fit, R_{inn} , is consistent with a Kerr black hole. The fits allow a range of viewing angles so that the disk may be viewed close to the disk axis (up to $\sim 20^\circ$ away). This removes the problem of having to view the AD through a co-planar molecular torus and is consistent with suggestions that ultrasoft AGN are seen relatively face-on (Puchnarewicz et al. 1992).

3. EMISSION LINES FROM THE DISK?

A large accretion disk heated by soft X-rays intercepted from the central source is likely to have a temperature-inversion layer at its surface. Therefore, we expect strong emission-line formation at large radii. In particular, in the case of RE J1034+396, the largest contribution to low-ionisation lines such as $H\alpha$ and $H\beta$ would come from radii $\gtrsim 10^{16} \text{ cm}$, where the Keplerian rotational velocities are $(GM/R)^{1/2} \lesssim 1000 \text{ km s}^{-1}$. If the Balmer lines are indeed produced near the disk surface, we expect full widths at half maximum $\sim 2(\sin i)(GM/R)^{1/2} \lesssim 2000 \text{ km s}^{-1}$. This is in agreement with the observed values of 1500 and 1800 km s^{-1} for $H\beta$ and $H\alpha$ respectively (Puchnarewicz, Mason & Siemiginowska 1998).

Moreover, if the X-ray luminosity from the central source is $\gtrsim 0.1 L_{\text{Edd}}$, we may expect the formation of a radiatively-driven accretion disk wind. Accurate modelling of the emission-line profiles may help us ascertain if higher-ionisation lines are formed in the wind, and determine the ionisation parameter of the emission regions. The narrow, single-peaked UV lines seen by Puchnarewicz, Mason & Siemiginowska 1998 appear qualitatively consistent with the disk-wind model of Murray & Chiang 1997. The presence of broad and narrow components in the UV lines may be explained with a broad component emitted near the irradiated disk surface at smaller radii, and a narrow component emitted in the photoionised wind.

4. SUMMARY

RE J1034+396 is an ultrasoft X-ray AGN with relatively narrow permitted lines. Its accretion disk component is unusually hot ($\sim 100 \text{ eV}$) and shifted out of the UV completely, leaving bare a flat optical/UV continuum. We find that this component is consistent with the irradiation of a flared or warped disk. Optical and UV lines may be produced in a radiatively-driven disk wind and, qualitatively, their profiles and velocities are consistent with those observed in RE J1034+396 and other ultrasoft Seyferts. A sketch of the geometry is shown in Figure 4. If RE J1034+396

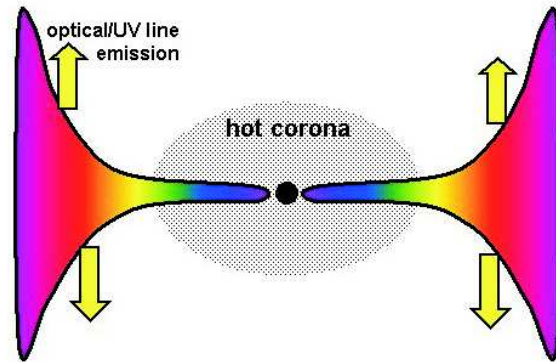


Figure 4. A cross-section through the nucleus of RE J1034+396. The disk is shown flared here but may also be warped. The cool, outer regions of the disk intercept a greater fraction of the hot, ionizing EUV/X-ray continuum than in a flat disk, enhancing the optical continuum emission. Permitted lines may be emitted from a radiatively-driven disk wind.

is a template for all ultrasoft AGN, it may be that the degree of AD flaring is a consequence of the extreme ultrasoft X-ray flux and temperature. The tendency for ultrasoft AGN to have relatively low emission line velocities (ie they tend to be narrow-line Seyfert 1s: Puchnarewicz et al. 1992) may also be due to irradiation of a flared AD, where the emission line flux is dominated by an AD wind.

An analogy has already been drawn between ultrasoft AGN and galactic black holes which share a black hole plus accretion disk geometry. Such a self-consistent picture in AGN has important implications for our understanding of black hole physics on mass scales from stellar to supermassive.

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